

ASBESTOS
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CARCINOGENICITY

Asbestos and all commercial forms of asbestos are *known to be human carcinogens* based on sufficient evidence of carcinogenicity in humans (IARC 1982, 1987). Occupational exposure to chrysotile, amosite, anthophyllite, and mixtures containing crocidolite has resulted in a high incidence of lung carcinomas. Mesotheliomas have been observed after occupational exposure to crocidolite, amosite, and chrysotile asbestos. Gastrointestinal cancers occurred at an increased incidence in groups occupationally exposed to crocidolite, amosite, chrysotile, or mixed fibers containing crocidolite, although not all studies are consistent. An excess of laryngeal cancer has also been observed in some groups of exposed workers. No clear excess of cancer has been associated with the presence of asbestos fibers in drinking water. Mesotheliomas have occurred in individuals living in the neighborhood of asbestos factories and mines and in people living with asbestos workers (IARC 1987). Both cigarette smoking and occupational exposure to asbestos fibers increase lung cancer incidence independently. When present together, they act multiplicatively (IARC 1973, 1977, 1979, 1982). A study based on findings from two asbestos cement manufacturing plants has shown evidence of a greater risk of mesothelioma from exposure to crocidolite than to chrysotile asbestos (Hughes *et al.* 1987).

An IARC Working Group reported that there is sufficient evidence of carcinogenicity of asbestos and the following forms of commercial asbestos: chrysotile (CAS No. 12001-29-5), amosite (CAS No. 12172-73-5), anthophyllite (CAS No. 17068-78-9), and crocidolite (CAS No. 12001-28-4) in experimental animals (IARC 1973, 1977, 1979, 1982, 1987). Chrysotile, crocidolite, amosite, and anthophyllite induced mesotheliomas and lung carcinomas in rats when inhaled, and induced mesotheliomas in rats and hamsters after intrapleural administration. Intraperitoneal administration of chrysotile, crocidolite, and amosite induced peritoneal tumors, including mesotheliomas, in mice and rats. Given by the same route, crocidolite induced abdominal tumors in hamsters, and actinolite induced abdominal tumors in rats. When filter material containing chrysotile was added to the diet, a statistically significant increase in the incidence of malignant tumors was observed in rats. Tumor incidence was not increased by oral administration of amosite in rats, of amosite in hamsters, or of chrysotile in hamsters. There was no evidence of carcinogenicity for pelleted short-range (SR) chrysotile (for rats of both sexes) or for pelleted intermediate-range (IR) fiber length chrysotile for female rats when added to the diet for the lifespan. In the same study, there was a low incidence of benign adenomatous polyps of the large intestine in male rats administered IR chrysotile. Cocarcinogenesis studies of 1,2-dimethylhydrazine dihydrochloride (DMH) and IR chrysotile were inconclusive for determining whether IR chrysotile had a tumor-enhancing effect, although an increased incidence of neoplasms was observed in the kidneys of female rats exposed to DMH plus IR chrysotile as compared with those exposed to DMH alone (NTP 1985).

PROPERTIES

Asbestos is the generic name given to a specific group of six naturally occurring fibrous silicate minerals. These include the fibrous serpentine mineral chrysotile and five fibrous amphibole minerals (actinolite, amosite, anthophyllite, crocidolite, and tremolite). Asbestos minerals possess a number of desirable properties that were useful in commercial applications. These include heat stability, thermal and electrical insulation, wear and friction characteristics, tensile strength, the ability to be woven, and resistance to chemical and biological degradation. Tensile strength of the various types have the following order: crocidolite > chrysotile > amosite > anthophyllite > tremolite > actinolite; the relative order of acid resistance is tremolite > anthophyllite > crocidolite > actinolite > amosite > chrysotile. Chrysotile, anthophyllite, amosite, and crocidolite are the only forms that were used commercially (IARC 1973, 1977, ATSDR 2001, HSDB 2000).

Chrysotile, the most abundant form of asbestos, occurs naturally in lengths from 1 to 20 mm, but may be as long as 100 mm. It has an idealized chemical composition of $Mg_3(Si_2O_5)(OH)_4$ and exists as a curled sheet silicate that forms a spiral around a central hollow tube. The hydroxyl group may be replaced by oxygen, fluorine, or chlorine, but this replacement occurs rarely. In addition, small amounts of iron, aluminum, nickel, calcium, chromium, manganese, sodium, and potassium may be present as impurities. Natural chrysotiles occur with a range of physical properties. Chrysotiles may be white, gray, green, or yellowish, with a silky luster. Although chrysotile fibers are more flexible than the amphiboles, there are differences in the relative flexibility of fibers derived from different geological locations. The terms “harsh” and “soft” fibers are used to describe the relative flexibility. Particles of chrysotile have a net positive charge on their surface and will form a stable suspension in water; however, the fibers will degrade in dilute acids (IARC 1973, 1977, IPCS 1986).

The amphibole minerals consist of chain structures, with nine structural sites that may accommodate cations. Amphibole crystals consist of two chains or ribbons based on Si_4O_{11} units separated by a band of cations. Magnesium, iron, calcium, and sodium are the principal cations, and the ratios of these cations determine the mineral species. Amphibole fibers do not divide into fibrils as small in diameter or as symmetrical as chrysotile fibers and they do not have a hollow central core. Unlike chrysotile fibers, amphiboles have a negative surface charge in water (IPCS 1986, HSDB 2000).

Amosite, with a general chemical composition of $(Fe_6Mg)Si_8O_{22}(OH)_2$, is ash gray, greenish, or brown and is somewhat resistant to acids. It tends to occur with more iron than magnesium at a ratio of approximately 5.5:1.5. The fibers are long, straight, coarse, somewhat pliable, and not as flexible as chrysotile (IARC 1973, 1977, IPCS 1986).

Anthophyllite, with a general chemical composition of $(FeMg_6)Si_8O_{22}(OH)_2$, is grayish white, brown-gray, or green in color and has very good acid resistance. It is relatively rare and occasionally occurs as a contaminant in talc deposits. The fibers are short and very brittle (IARC 1973, 1977, IPCS 1986).

Crocidolite, with a general chemical composition of $Na(Fe_2^{3+}Fe_3^{2+})Si_8O_{22}(OH)_2$, is lavender or blue and has good resistance to acids, but is not as heat resistant as other asbestos fibers. It typically disperses into fibers that are shorter and thinner than other amphiboles, but not as thin as chrysotile fibers. The fibers have fair to good flexibility, fair spinnability, and a soft to harsh texture. Organic impurities, including low levels of polycyclic aromatic hydrocarbons, are usually present (IARC 1973, 1977, IPCS 1986).

Tremolite, with a general chemical composition of $\text{Ca}_2\text{Mg}_6\text{Si}_8\text{O}_{22}(\text{OH})_2$, and actinolite, with a general chemical composition of $\text{Ca}_2(\text{MgFe}_6)\text{Si}_8\text{O}_{22}(\text{OH})_2$, rarely occur in the asbestos habitat. However, tremolite is a common contaminant in chrysotile and talc deposits, and actinolite is a common contaminant in amosite deposits. Tremolite has a white to gray color, and actinolite is pale to dark green. Both have a brittle texture, but tremolite is resistant to acids while actinolite is not (IARC 1977, IPCS 1986).

USE

Although asbestos use dates back at least 2,000 years, modern industrial use began around 1880. Asbestos demand reached its peak in the late 1960s and early 1970s when more than 3,000 industrial applications or products were listed. Asbestos has been used in roofing, thermal and electrical insulation, cement pipe and sheets, flooring, gaskets, friction materials, coatings, plastics, textiles, paper, and other products (ATSDR 2001, HSDB 2000). The U.S. Consumer Product Safety Commission (CPSC) banned general use garments containing asbestos, but special garments used in fire fighting are permitted if they are constructed to prevent release of asbestos fibers (HSDB 2000). Domestically used asbestos fibers are technically classified into seven quality categories or grades. Grades 1, 2, and 3 include the longer, maximum-strength fibers and are generally used in the production of textiles, electrical insulation, and pharmaceutical and beverage filters. Grades 4, 5, and 6 are medium-length fibers used in the production of asbestos-cement (A/C) pipe, A/C sheet, clutch facings, brake linings, asbestos paper, packaging, gaskets, and pipe coverings. Grade 7 includes short fibers generally used as a reinforcer in plastics, floor tiles, coatings and compounds, some papers, and roofing felts (OSHA 1986).

The four commercially important forms of asbestos were chrysotile, amosite, anthophyllite, and crocidolite (IARC 1973); however, commercial use of anthophyllite was discontinued by the 1980s (IPCS 1986, HSDB 2000). Chrysotile, amosite, and particularly crocidolite all have extremely high-tensile strengths and are used extensively as reinforcers in cements, resins, and plastics. Although chrysotile is most adaptable to industrial use, crocidolite and amosite are particularly useful in combination with chrysotile for adding specific properties, such as rigidity (OSHA 1986).

Consumption of asbestos in the United States has been declining for two decades. Reported consumption was 790 million lb in 1980. By 1998 and 1999, U. S. consumption had declined to 34.8 million lb per year. The 1999 domestic consumption pattern was 61% for roofing products, 19% for gaskets, and 13% for friction products (automobile clutch, brake, and transmission components). Roofing products, gaskets and friction products will continue to be the only significant domestic markets for asbestos in the foreseeable future. Only chrysotile is presently used for manufacturing in the United States. Ninety-four percent of chrysotile consumed was grade 7, a short (3 μm) fiber. Only 0.4% of the asbestos used were long fibers (6-9.5 μm); these were mostly used in plastics (ATSDR 2001).

PRODUCTION

U.S. demand for asbestos increased dramatically between 1900 and the early 1970s. By 1950, the U.S. was the largest user of asbestos in the world. However, as health and liability issues became apparent, asbestos demand declined rapidly after 1973.

Prior to the 1980s, asbestos was produced at facilities in California, Arizona, North Carolina, and Vermont; however, most of these facilities suspended mining operations in the 1970s. By 1985, there were only three U.S. companies producing asbestos. In 2000, there was only one U.S. company mining asbestos and two U.S. suppliers (Virta 2000, ATSDR 2001, Chem Sources 2001).

The production volume of asbestos in the U.S. has decreased significantly from the high output of 136,000 metric tons (299 million lb) in 1973 to approximately 5,000 metric tons (11 million lb) in 2000. Domestic consumption (production plus imports minus exports and adjustments for government and industry stocks) also declined from approximately 803,000 metric tons (1.8 billion lb) in 1973 to 15,000 metric tons (33 million lb) by 2000. Most of the asbestos used in the United States is imported from Canada. The amounts imported declined from 718,000 metric tons (1.6 billion lb) in 1973 to 15,000 metric tons (33 million lb) in 2000. Asbestos exports also peaked in 1973 at 59,900 metric tons (132 million lb) (Buckingham and Virta 2000, Virta 2001). The U.S. International Trade Administration (ITA 2001) reported that 18,842 metric tons (41.5 million lb) of asbestos were exported in 2000.

EXPOSURE

The primary routes of potential human exposure to asbestos are inhalation and ingestion. Dermal absorption of asbestos is minimal, but contact may lead to secondary ingestion or inhalation of dust. Asbestos is released to the environment from both natural and man-made sources and has been detected in indoor and outdoor air, soil, drinking water, food, and medicines. Because asbestos products are used so widely, the entire population is potentially exposed to some degree. However, gross pollution in the areas of mines, factories, and shipyards is far less than 30 to 50 years ago.

Applications of asbestos materials to buildings and vehicle brake linings account for a significant amount of air emissions. Demolition of buildings with asbestos insulation or fireproofing may cause high atmospheric concentrations for relatively short periods of time. Asbestos concentrations vary widely; therefore, it is not possible to accurately calculate human exposure levels except on a case-by-case basis (ATSDR 2001). EPA's Toxic Chemical Release Inventory (TRI) listed 87 industrial facilities that produced, processed, or otherwise used asbestos in 1999. The facilities reported releases of asbestos to the environment which were estimated to total 18 million lb. Most environmental releases occurred to the land. Asbestos releases declined by approximately 50% from 1988 to 1989, but have fluctuated since 1989 (TRI99 2001).

Worker exposure is a concern in the mining and milling of asbestos, during the manufacture of all asbestos products, and in the construction and shipbuilding industries. In addition, worker exposure occurs in asbestos end-product use occupations, such as asbestos insulation workers, brake repair and maintenance workers, building demolition workers, and asbestos abatement workers (IARC 1977, ATSDR 2001, HSDB 2000). The National Occupational Exposure Survey (NOES) (1981-1983) estimated that 153,937 total workers, including 7,603 women, were potentially exposed to asbestos (NIOSH 1984). The total estimate was based on actual observations of asbestos (41%) and its use in trade name products (59%). The NOES estimated that 30,594 total workers, including 3,410 women, were potentially exposed to chrysotile. The total estimate was based on observations of actual use of chrysotile (12%) and its use in trade name products (88%). OSHA, in a 1990 report, estimated that approximately 568,000 production and service industry workers and 114,000 construction industry workers were potentially exposed to asbestos (ATSDR 2001).

People may encounter higher-than-average environmental asbestos concentrations in air if they live near an asbestos-containing waste site or asbestos-related industry, if they use any of a variety of asbestos-containing products, if they live or work in a building with deteriorating asbestos insulation, or if they live or work in a building that has undergone a poorly performed asbestos removal operation (ATSDR 2001). In the past, families of asbestos workers were potentially exposed to high fiber levels through contaminated clothing brought home for laundering. Household contacts of asbestos workers were found to have significantly elevated pulmonary asbestos burdens, often in the range of those individuals who are occupationally exposed to asbestos, such as shipyard workers. The fiber burdens of occupants of a building containing asbestos insulation, on the other hand, were comparable to those of individuals with no known occupational exposure to asbestos (IARC 1977, Roggli and Longo 1991).

REGULATIONS

CPSC's banning of asbestos in patching compounds and in gas fireplaces prevented additional exposure of several million consumers who may have been exposed to asbestos from these sources. U.S. manufacturers of hand-held hair dryers cooperated with CPSC by voluntarily ceasing to use asbestos liners; this voluntary program resulted in the repair by manufacturers of 2 million dryers. Also, CPSC published an intent to further regulate the uses of asbestos, and convened a Chronic Hazard Advisory Panel to assess and, if feasible, to estimate the probable harm to human health that can result from exposure to asbestos. A final report was published in 1983. Studies on the release of asbestos from products were completed in 1984 and toxicity reviews of major selected asbestos substitutes occurred in 1986. CPSC monitored air levels of asbestos in 45 homes, using transmission electron microscopy. The study concentrated on homes with quantities of worn and damaged asbestos materials. The results of this study did not show increased indoor levels of asbestos in these homes compared with outdoors. An enforcement policy became effective in 1986, requiring labeling of all consumer products containing intentionally added asbestos that, under reasonably foreseeable conditions of handling and use, are likely to release fibers. The CPSC, in 1989, denied a petition to ban limestone products containing more than 0.1% tremolite because there were no data indicating the presence of asbestiform tremolite in these products and no data indicating that non-asbestiform tremolite is hazardous. In response to recent reports that asbestos was found in crayons, CPSC tested crayons from three manufacturers. Asbestos could be present in talc used as a binding agent in the crayons. CPSC found trace amounts of anthophyllite asbestos and larger amounts of transitional fibers in crayons from two of three manufacturers. No airborne fibers were detected during stimulated use. Although the risk was considered extremely low, manufacturers voluntarily agreed to reformulate to eliminate talc (CPSC 2000).

EPA regulates asbestos under the Clean Air Act (CAA), Clean Water Act (CWA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), Safe Drinking Water Act (SDWA), Superfund Amendments and Reauthorization Act (SARA), and Toxic Substances Control Act (TSCA). A reportable quantity (RQ) of 1 lb has been established for asbestos under CERCLA. Under the SDWA, EPA has set the maximum contaminant level (MCL) and the maximum contaminant level goal (MCLG) for asbestos at 7 million fibers per liter. Under TSCA, EPA prohibits the manufacture and use of asbestos in certain products. A voluntary EPA program is removing or encapsulating sources of asbestos released in school buildings. Asbestos is also subject to reporting requirements under CERCLA, RCRA, SARA, and TSCA.

FDA regulates, under the Food, Drug, and Cosmetic Act (FD&CA), the use of asbestos in indirect food additives, adhesives, components of coatings, and polymers. FDA has also restricted the use of asbestos filters in the manufacture of drugs and drug ingredients.

NIOSH recommended in testimony to the Department of Labor in 1990 that the following definition of asbestos be adopted for regulating exposures to asbestos: "The asbestos minerals are defined as chrysotile, crocidolite, amosite (cummingtonite-grunerite), anthophyllite, tremolite, and actinolite. In addition, airborne cleavage fragments from the nonasbestiform habits of the serpentine minerals antigorite and lizardite, and the amphibole minerals contained in the series cummingtonite-grunerite, tremolite-ferroactinolite, and glaucophane-riebeckite shall also be counted as fibers provided they meet the criteria for a fiber when viewed microscopically." The NIOSH recommended exposure limit (REL) for asbestos is 0.1 fibers/cm³ in a 400-liter air sample collected at a flow rate of 4 liters per minute (any 100-minute period) for fibers longer than 5 µm.

The OSHA permissible exposure limit (PEL) for asbestos fibers in the workplace is 0.1 fibers/cm³ of air as an 8-hr time-weighted average (TWA) for fibers longer than 5 µm. This standard also requires personal protective equipment, training, medical surveillance, signs, labeling, and engineering controls. OSHA published an Emergency Temporary Standard (ETS), lowering the PEL TWA for ambient asbestos to 0.5 fibers/cm³. Enforcement of the ETS was stayed by the Fifth Circuit Court of Appeals. OSHA then published a supplemental proposal to the ETS. This supplement contained an additional option for a PEL of 0.2 fibers/cm³ (5 µm or longer). OSHA regulates asbestos as a chemical hazard in laboratories under the Hazard Communication Standard. Regulations are summarized in Volume II, Table 16.

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